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Development of hydropower energy in Turkey: The case of Çoruh river basin

Adem Akpınar [a,*], Murat İhsan Kömürcü [b], Murat Kankal [b]

[a] Gümüşhane University, Civil Engineering Department, 29000 Gümüşhane, Turkey
[b] Karadeniz Technical University, Civil Engineering Department, 61080 Trabzon, Turkey

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ABSTRACT

The main objective in doing the present study is to investigate the sustainable development of hydropower plants in the Çoruh river basin of Turkey, which is least problem river of Turkey in respect to international cooperation as compared with Turkey's other trans-boundary waters. Initial studies concerning the hydropower production potential in Çoruh basin had been carried out by Turkish authorities in the late 1960s. Total installed power capacity and annual average energy generation of 37 dams and run of river (without storage) hydropower plants developed at various project stages by The Electrical Power Resources Survey and Development Administration (EİE) in Çoruh basin are 3132.70 MW and 10.55 TWh/yr, respectively. Today, this generation value corresponds 6.45% of Turkey's energy consumption in 2006 while it meets 6.3% of total electricity energy production of Turkey which is equal to 167.9 TWh/yr in 2006. Besides, this potential developed at various project stages in Çoruh basin will provide 24.1% of Turkey's hydroelectric energy generation being equal to 43.8 TWh/yr in 2006.

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1. Introduction

Energy is considered to be a key factor in the generation of wealth and also a significant component in economic development in Turkey as in other countries. This makes energy resources extremely significant for energy countries in the world [1,2].

Success in sustainable development with its economic, environmental, social, and geopolitical dimensions requires a complex and long process. Energy policies contribute to this process by tailoring its three basic goals, which are reliability of supply that seeks to minimize the negative effects and risks to society of possible supply cuts, competitive energy systems to ensure low-cost energy for both producers and consumers so as to contribute to competition and to other broader social policy goals, and environmental protection that is integrated to energy production and utilization practices so as to maintain ecological and geophysical balances in the nature, that reflect the requirements of sustainable development [3].

The basic target of Turkish national policy on energy is the provision of cheap electrical energy in sufficient amount and on time, under qualified, reliable and competitive conditions of energy market [2–4].

* Corresponding author. Tel.: +90 456 233 7425x155; fax: +90 456 233 7427.
E-mail addresses: aakpinar@ktu.edu.tr, ademakpinar@hotmail.com (A. Akpınar).

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Total economic hydroelectric power potential of Turkey is 129.5 TWh/yr by the end of February 2007. 35.5% of this potential is in operation while 11.1% and 53.4% of this potential are under construction and in various design level, respectively [5]. This potential is concentrated in 22 basins, the Euphrates and Tigris being the biggest with about 45% of the total. Çoruh river basin has approximately 8.5% of total economic hydroelectric power potential of Turkey [6].

Having potential of about 10.55 TWh energy, the Çoruh river is one of the most important rivers in northeastern Turkey, flowing from the southwest towards the northeast [7]. In order to use the energy potential of the river, in the result of etude studies carried out by EİE, thirty-seven hydropower plant projects (fifteen dams and twenty two regulators) on Tortum river, Oltu river, and main tributary of Çoruh river have planned. The construction of Borçka and Muratlı Dam and HPP from these projects is already completed and Deriner Dam and HPP is in progress while the remaining dams are in the project phase.

In this article, firstly the hydroelectric energy potential and its development both in Turkey and the World are examined. Then, Çoruh river basin has been chosen being case study to carry out some examinations concerning its potential. For this purpose, this paper analyses general characteristics, climate and water resources, currently water usage status, and energy potential of the Çoruh river basin. In addition to this, the Çoruh Basin Development Plan, the importance of Çoruh river basin, and development projects which will have been carried out in this region are discussed and evaluated.

2. Hydroelectric energy potential and its development in Turkey and World

2.1. Hydropower as a renewable and sustainable resource

Hydropower is a proven technology for electricity generation, contributing with almost 20% to the fulfillment of the planet electricity demand. Hydro-turbines convert water pressure into mechanical shaft power, which can be used to drive an electricity generator, or other machinery. The power available is proportional to the product of pressure head and water discharge. Hydropower continues to be the most efficient way to generate electricity. Modern hydro-turbines can convert as much as 90% of the available energy into electricity. The best fossil fuel plants are only about 50% efficient. Hydropower is also renewable because it draws its essential energy from the sun and particularly from the hydrological cycle [2]. Besides, its resources are widely spread around the world. Potential exists in about 150 countries and about two-thirds of the economically feasible potential remains to be developed. It plays a major role in reducing greenhouse gas emissions in terms of avoided generation by fossil fuels. Hydro is a relatively small source of atmospheric emissions compared with fossil fired generating options and has the lowest operating costs and the longest plant life, compared with other large scale generating options [8].

2.2. Hydropower potential and current situation in world

Hydropower is today the most important kind of renewable and sustainable energy for the world [9]. The position of hydro plants becomes more and more important in today's global renewable technologies. Untouched hydropower potential is identified in developing countries of South and Central Asia, Latin America, and Africa, but also in Canada, Turkey and Russia. In Western Europe and the United States, the additional hydropower potential is limited, because of advanced development but also due to environmental and political reasons [10].

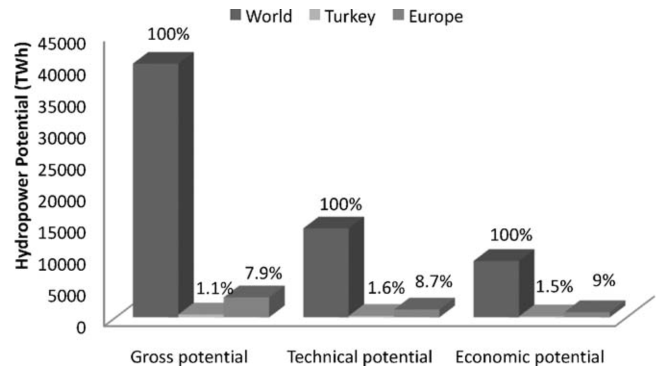


Fig. 1. Hydro potential of Turkey and Europe compared to world's potential.

Hydro electric energy is worldwide responsible for some 2997.06 terawatt-hours (TWh) of electricity output per year in 2006, which means about 18.3% of the world's entire electricity demand being one of the most reliable and cost effective renewable energy source. In developing countries hydropower is expected to be the fastest-growing renewable energy source [11,12]. The largest hydropower producer in 2006 is People's Republic of China (431.43 TWh/yr), followed by Canada (351.85 TWh/yr), Brazil (345.32 TWh/yr), the United States (289.25 TWh/yr), Russia (173.65 TWh/yr), and Norway (118.21 TWh/yr). Turkey takes place in 13th sequence amongst the world countries with 43.8 TWh/yr its hydropower electric generation.

2.3. Turkey's hydropower potential and its usage

Because of social and economic development of Turkey, the demand for energy and particularly for electricity is growing rapidly. The main indigenous energy resources are hydro and lignite. Turkey has no big oil and gas reserves. Almost all oil and natural gas is imported, as is high quality coal [1,2]. In Turkey, electricity is produced by thermal power plants, consuming coal, lignite, natural gas, fuel oil and geothermal energy, and hydropower plants. There is no nuclear power in Turkey as yet [13]. Turkey also has a large potential for renewable energies. By the year 2010, Turkey is planning to exploit two-thirds of its hydropower potential between renewable energy sources, aiming to increase hydro-production to about 75.0 TWh/yr by 2020; this will raise to 100.0 TWh/yr, and by 2030 it could be 140.0 TWh/yr [8,11].

In the determination of hydroelectric energy potential gross potential, technical potential and economical potential are the important conceptions. Briefly, the gross potential shows the hydroelectric energy production upper limit of a river basin, a potential that is made up by the existing height and average flow rate. Gross hydroelectric energy potential of Turkey, which is a function of topography and hydrology, is about 433.0 TWh/yr that is equal to 1.1% of the total hydropower potential of the world and 13.8% of European hydropower potential (Fig. 1) [6,14]. Technical potential shows the upper limit of the hydroelectric energy production of a river basin. Excluding the inevitable losses, this represents the hydroelectric energy production limit that is technically feasible. Technical hydroelectric energy potential in Turkey is estimated as 216.0 TWh/yr. Economical hydroelectric potential is the total hydroelectric energy from a river basin that can be technically developed and is economically coherent. In other words, the economical hydroelectric energy potential shows the hydraulic resources with economical feasibility [15]. As the end of February of 2007-year, economical potential of Turkey is almost 30% of the theoretical potential (nearly 129.9 TWh/yr).

Although Turkey is not affluent in terms of hydroelectric energy potential, it is ranked in the first quartile within European countries.

In terms of developing water resources in Turkey, hydraulic energy generation takes a considerable portion. As of February 2007, there were 142 hydro plants in operation. These have a total installed capacity of 12,788 MW and an annual average generation capacity of 45.93 TWh, amounting to almost 35.5% of the total exploitable potential, which is at present meeting about 35% of the electricity demand. Forty-one hydro plants with an installed capacity of 4397 MW and an annual generation capacity of 14.351 TWh, which is almost 11.1% of the total potential, are under construction. In the future, 589 more hydropower plants will be constructed to exploit the remaining potential of 69.173 TWh/yr, bringing the total number of hydropower plants to 772 with a total installed capacity of 36,544 MW. Those are being designed are divided into four subgroups and distribution of Turkey hydropower potential according to design level are given in Fig. 2 [5,16].

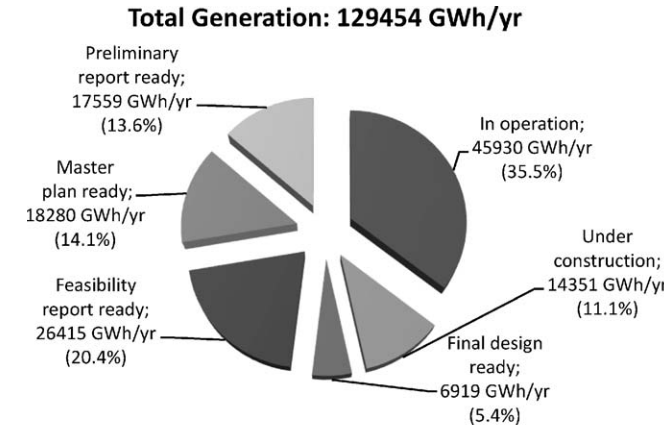


Fig. 2. Distribution of Turkey's hydropower potential according to design level.

3. The case study: Çoruh river basin

In this study, Çoruh river basin has been chosen as the area of examination. Çoruh river basin is one of the most picturesque yet significantly underdeveloped regions of Turkey. Rural incomes in the region are one-third of those averages for the country. Lack of cultivable land has in the past decades resulted in out-migration rates far exceeding other regions. The Government of Turkey has designed a large scale development program to close the interregional inequity between the Çoruh river basin communities and those in other parts of the country. As a result, the basin will host a chain of hydropower investments that will have major sustainable impacts on the region. Several large scale investments have been completed and others are under construction or being planned. From the ongoing experience, there is a great deal that can be learned to guide the subsequent investments. There is also need to integrate state support to the individual hydropower projects into a holistic efficient and integrated river basin framework [17].

3.1. General characteristics of Çoruh basin

The Çoruh river rises at Civilikaya Hill, located in the Mescit Mountains at the North of the Erzurum Plateau, and flows through East Anatolia and the East Black Sea Regions of Turkey to finally reach the Black Sea near Batumi in Georgia (Fig. 3) [18]. Approximately 91% of the basin's drainage area (21,100 km^2) is, however,

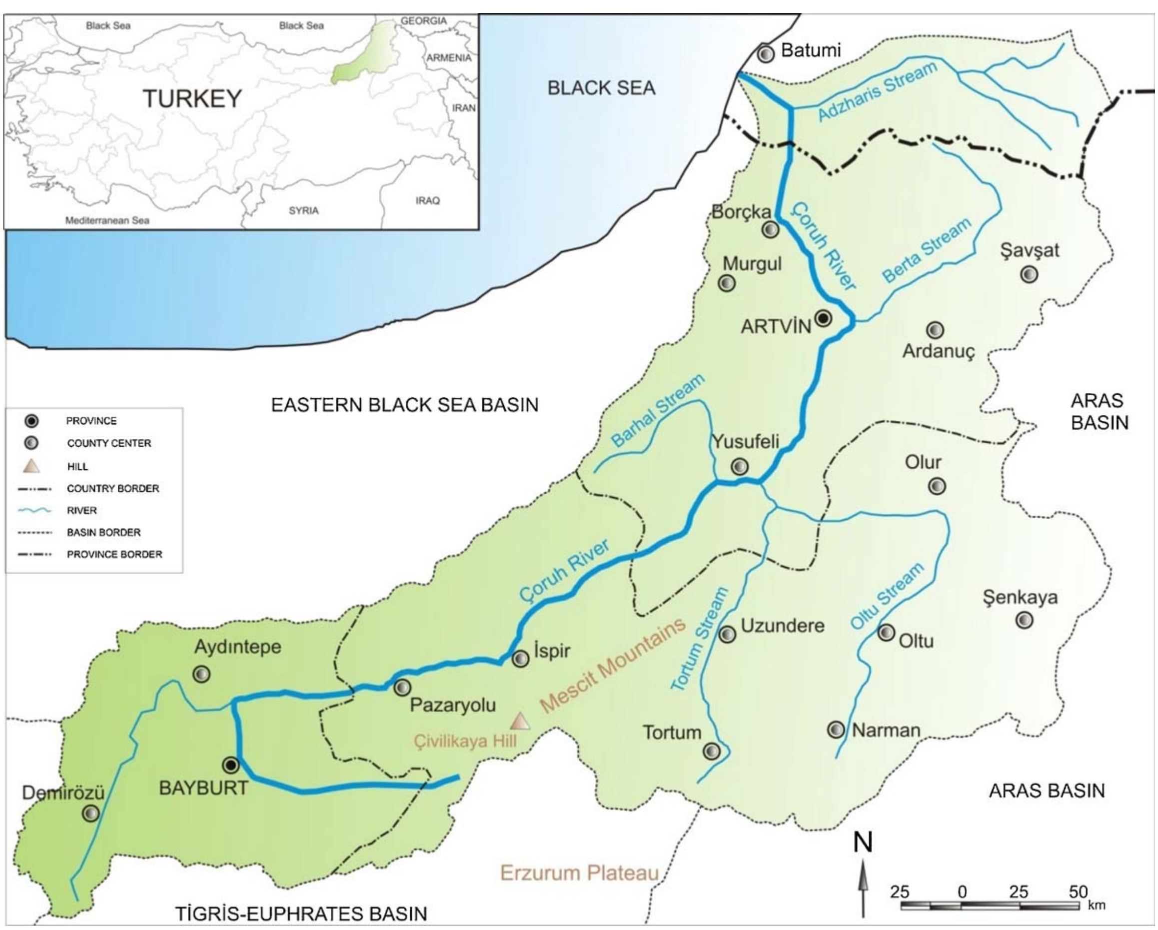


Fig. 3. Location map of the Çoruh river basin.

Table 1
Water potential of Çoruh basin [21,22].

	Turkey		Çoruh basin		
	The gross potential (bcm)	Technically and economically exploitable potential (bcm)	Water potential (bcm)	% of the gross potential	% of exploitable potential
Surface water potential	193	98	6.277	3.25	6.405
Groundwater potential	41	14	0.023	0.056	0.164
Total potential	234	112	6.300	3.306	6.569

in Turkey while Georgia's share amounts to 9% only. The principal tributaries of the Çoruh river are the Tortum and Oltu rivers in Turkey, and Adzharis river in Georgia. In total, the Çoruh river is 427 km long, 400 km of which lies within Turkey's borders. It also forms a short border (3 km) between Turkey and Georgia. Finally, the river flows for 24 km through Georgia [19,20].

The river originates in the western part of the Mescit mountains at a height of over 3000 m and lies to the north-west of the Erzurum-Kars Plateau. From these mountains the Çoruh first flows west, then turns east with a sharp bend at the Bayburt Plain and afterwards follows a tectonic hollow which separates the East Black Sea coastal mountain series from the inner mountain range. The Çoruh valley located in the eastern part of İspir, is one of the deepest valleys in Turkey. Having passed the city of Yusufeli and the confluence with the Oltu river, the Çoruh flows north and shapes a mountain landscape with deep canyons. Passing through the cities of Artvin and Borçka, it leaves Turkish territory near the city of Muratlı. Near Batumi, the capital city of the Georgian semi-autonomous province Ajaria, the river empties into the Black Sea through a delta which is largely composed of the alluvium that it has accumulated [19]. The Çoruh basin is one of basins being exposed to the most erosion. The Çoruh river, which is fastest flowing river amongst Turkey's rivers and is accepted between quickest flowing ten rivers of the world, has also the total head of 1420 m for energy generation, from the most upstream Laleli Site to the most downstream Muratlı Site close to the Georgian border.

3.2. Climate of the region and its water resources

Because of climatic conditions, the river carries plenty of water in all seasons albeit with remarkable seasonal variations. The river experiences a transitional climate between Black Sea's mild and wet weather and East Anatolia's cold climate. Turkey's average annual rainfall is 642 mm, whereas the Çoruh basin receives 475 mm rain in an average year. According to the long-term observations measured at the flow monitoring station in Muratlı, the average flow rate is 202 m^3/s. The highest run-off measured at this station was 2431 m^3/s and the lowest was 37.6 m^3/s. Rainfall and especially snowmelt from the high mountains suggests that there is high water availability. In spring, total water flow reaches 221.38 million cubic meter/year (mcm/yr) constituting 40.9% of the mean annual flow. The flow rate of the Çoruh in May alone approximately equals twice the amount it carries during the whole winter season [19].

In total, according to Turkish long-term observations, annual flow rates of the Çoruh ranges from 3.3 billion cubic meter/year (bcm/yr) (1955) to 11.2 bcm/yr (1968). The medium annual flow rate determined through long year measurements and being correspond to the 3.31% of the total water potential in Turkey (Table 1) is 6.3 bcm/yr. Apart from the comparatively high and variable flow rates, the river carries high levels of sediment and deposits (estimated at 5 mcm/yr) which stem from erosion in the Turkish mountain regions. Despite the rather small drainage basin area, the river has high hydropower production potential due to the topographic conditions and, in particular, the sharp fall of the river from high mountains to sea level.

The water potential and usage of river basins in Turkey have been summarized and evaluated on the basis of river basins in a study carried out by [23] (Fig. 4). In Turkey, there are 26 river basins in terms of hydrology. In this research, it is concluded that water resources of Turkey in present conditions have sufficient. Generally of the river basins (17 units) haven't problems of water stress problems in aspect of evaluation of total water potential on the basis of river basin. Meriç Ergene, Büyük Menderes, Sakarya and Kızılırmak

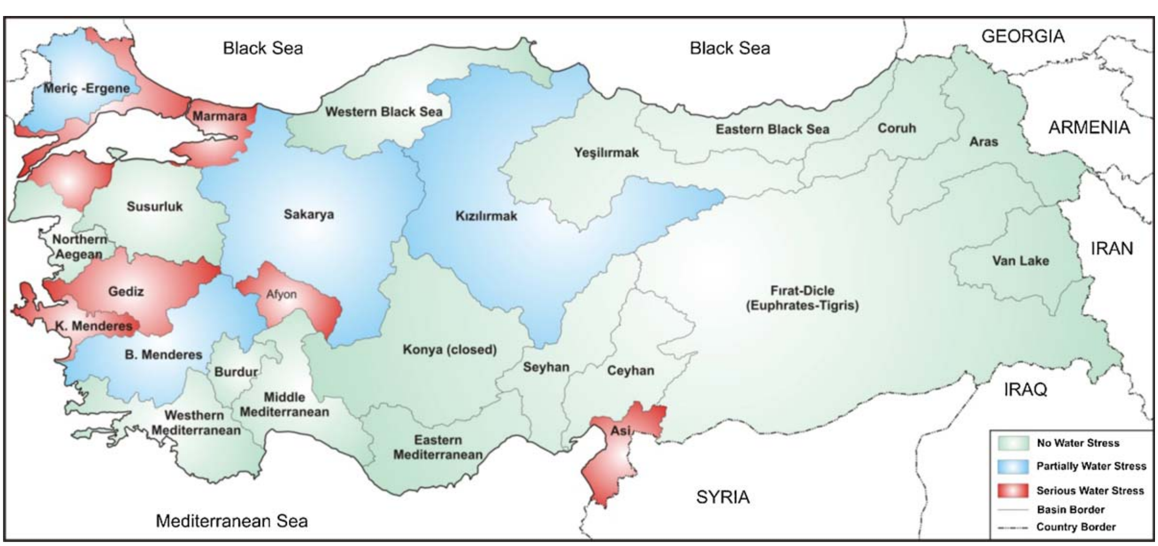


Fig. 4. Water stress level on the river basins of Turkey [24].

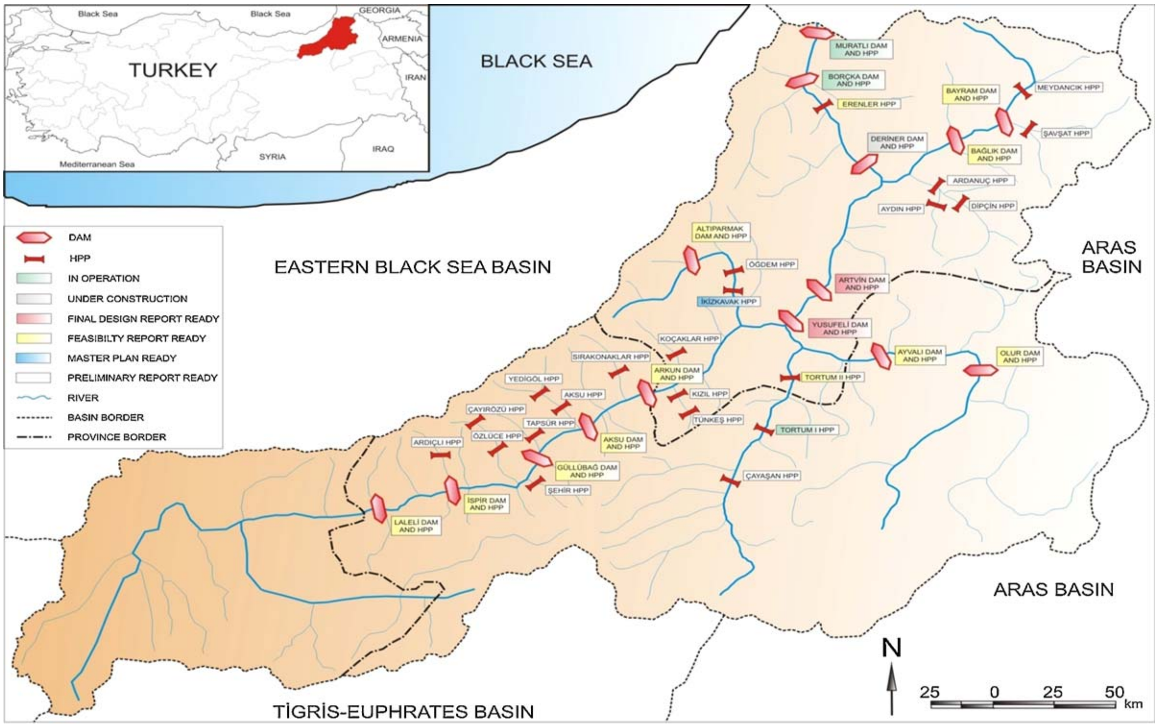


Fig. 5. The Çoruh river basin and planned projects within the scope of the Çoruh Basin Development Plan.

basins have been coming chronic water stress. Küçük Menderes, Gediz, Marmara, Akarçay, and Asi basins brought almost near to absolute water stress level [24].

Of 26 hydrologic basins, 22 are river basins and the other four are enclosed basins that have no flow to the sea. Two river basins (the Euphrates and the Tigris) contain the largest volume of flow of all the rivers in Turkey, 28.5% of the nation's total surface flow (17% in the Euphrates and 11.5% in the Tigris). East Black Sea, with an 8% contribution, East Mediterranean, with a 6% contribution, and Antalya, with 5.9% contribution, are other relatively water-rich basins [25]. Çoruh basin provides a 3.25% contribution to the nation's total surface flow which is equivalent to 186 bcm.

3.3. *Current water use status of Çoruh basin and development of planned projects*

Currently, only a minor share of the river's water is used for economic or social purposes. The most relevant water uses are water supply withdrawals (groundwater is, however, an easy accessible substitute in several regions) and instream activities such as kayaking and boating. The latter has enjoyed an increase in recent years and provides significant added value to the regional tourist sector. Because of the topography of the basin, agriculture is only of minor importance and the development of additional irrigation areas (although mentioned in the relevant planning documents) is estimated to play rather a minor role in future planning.

Nowadays, the most important pressures on freshwater ecosystems come from the development of hydropower generation installations. Because of favourable topographical conditions, the Çoruh has (according to DSI estimates) the potential to provide some 8.3% of the usable hydroelectric power in the country, which, to date, remains largely untapped. The first hydropower plant in the basin that was completed and begun commercial operation was Tortum I (installed capacity of around 26 MW) on the homonymous tributary. The other hydropower station already in operation is the Murgul hydropower plant (HPP) [19].

Initial studies concerning the hydropower production potential in Çoruh basin had already been carried out by Turkish authorities in the late 1960s. The Çoruh Basin Master Plan was eventually finished in 1982 and was followed by the Çoruh Basin Development Plan (Fig. 5).

In the scope of this Development Plan, it is a planned construction of 10 large dams on the main tributary of Çoruh river [26]. Feasibility reports of Laleli Dam and HPP, İspir Dam and HPP, Güllübağ Dam and HPP, Aksu Dam and HPP, and Arkun Dam and HPP which are located in Upper Çoruh Basin have been prepared and these projects will be made by corporate bodies (private sector) by the concept of Turkey's Electricity Market Law No. 4628. In this context, license procedures of these projects have continued. Yusufeli Dam and HPP being one of the two projects taking place in Middle Çoruh Basin is final design report ready. The latter, Artvin Dam and HPP is a project that bilateral agreements will have been signed between countries to further international cooperation in hydropower development. Firms within this project continue license procedure of their project within the scope of Turkey's Electricity Market Law No. 4628. Deriner Dam and HPP is located in Lower Çoruh Basin and this project is under construction (Fig. 6). Muratlı and Borçka Dams and HPPs were taken into operation in June 2005 and April 2007, respectively (Figs. 7 and 8).

Feasibility reports of Altıparmak Dam and HPP, Olur Dam and HPP, and Ayvalı Dam and HPP from 5 dam projects which are situated at affluents out of the main tributary of the Çoruh river are ready and license procedures of this projects have also continued by the concept of Turkey's Electricity Market Law No. 4628. Bayram and Bağlık Dams and HPPs which were prepared their feasibility reports are in the scope of intergovernmental bilateral cooperation. Within this scope, any advancement with regard to these projects has been carried out.

22 run of river (without storage) HPPs except for these dam projects have planned; one of these projects is taken into operation and others are being designed. Those are being designed are divided into various sub-groups as follows: 2 HPP projects with



Fig. 6. Deriner Dam and hydropower plant (under construction).



Fig. 7. Borçka Dam and hydropower plant.

feasibility report ready, one project with master plan ready, and 18 HPP projects with preliminary report ready [27].

The planned development will result in a total annual energy production of 10.545 TWh with the implementation of 3132.7 MW of hydro capacity on the Çoruh river basin. This capacity corresponds to 29.4% of the annual hydroelectric energy production of the Turkey which is 35.851 TWh/yr in 2007 [28]. The construction of 21 major hydropower investments are defined in a concrete manner within a framework in which 37 hydro plants is planned within the Çoruh basin, 24 of which are to be implemented on the estuaries [29] (Table 2). The construction activities, spanning close to 10 years, are expected to have significant positive socio-economic impacts primarily for this underdeveloped region and the affected communities. The benefits are expected to reach beyond the Turkish borders to benefits the neighboring country [17]. The Turkish authorities consider the Çoruh Basin Development Plan and associated dam constructions as vehicles to support economic development in north-eastern Turkey.

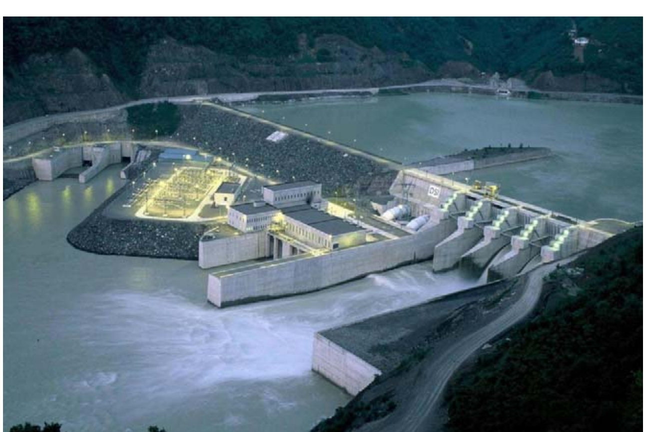


Fig. 8. Muratlı Dam and hydropower plant.

Although the programme predominantly focuses on hydropower generation and the supply of electricity, an irrigation (agriculture development) component also runs in parallel. With the construction of the dam cascade, 30,000 ha of land are planned for irrigation, mainly along the upper and middle streams of the river. This rather modest objective for agricultural development is due to the basin's topographical limits. A full realization of the planned development of irrigation agriculture could, however, significantly increase agricultural water use and change settlement patterns in the area [19].

3.4. Energy potential of Çoruh basin

For the developing countries due to the increasing industrial activities, an urgent need for utilizing the hydropower potential is appealed. Hydropower potential is also an attractive solution for energy need because of being a clean way of energy generation [30]. At present 142 HPPs are in operation in Turkey with total installed capacity of 12,788 MW and an average power generation of 45.93 TWh/yr [5]. The Çoruh river is the longest river of the East Black Sea region and is of high economic importance to Turkey because of it is largely undeveloped but has economically exploitable hydropower potential. The Çoruh Basin Development Project Dam and Hydropower Plants in operation by energy viewpoint constitute the 1.23% of the total hydroelectric potential of Turkey and 3.47% of the total hydropower potential in operation. With engagement of Deriner Dam, HPPs in operation will constitute the 2.87% of the total hydroelectric potential of Turkey. On the other hand the total energy projects in The Çoruh projects in operation will constitute 2.11% of total electric energy generation of Turkey including thermal, other hydraulics and wind based systems. Thermic energy potential of the region in operation is an average power generation of 0.30 TWh/yr with total installed capacity of 50 MW [22]. That is, thermic energy potential in operation of the region is very few as against hydroelectric energy potential of that.

According to data obtained from Turkish Electricity Transmission Company [28], energy consumption of Turkey in 2006 is 163.69 TWh/yr. Total installed power capacity and annual average energy generation of 37 dams and run of river (without storage) HPPs developed at various project stages by EİE in Çoruh basin are 3132.70 MW and 10.55 TWh/yr, respectively (Table 2). This generation corresponds 6.45% of Turkey's energy consumption in 2006, 6.3% of total electricity energy production of Turkey which is equal to 167.9 TWh/yr in 2006, and 24.1% of Turkey's hydroelectric energy generation being equal to 43.8 TWh/yr in 2006.

There are numerous projects in Çoruh river basin planned or developed by private sector except for the Çoruh Basin Development Projects. In this context, 2 hydropower plants (Murgul and Esendal HPPs) developed by corporate bodies within borders of Artvin Province, which have total installed capacity of 5 MW and energy generation of 10 GWh/yr, are in operation. Also, in Artvin Province, 58 HPPs have been planned by private sector, which these projects are at different design level as follows: 9 projects (123 MW, 418 GWh/yr) with Signed Water Right Consensus, 30 HPPs (432 MW, 1509 GWh/yr) with feasibility report ready, 19 projects (99 MW, 273 GWh/yr) with preliminary report ready. In Bayburt Province, Bayburt regulator and HPP, which has total

Table 2
Energy potential of Çoruh basin within the scope of Çoruh Basin Development Plan [27].

Level	Project name	Province	Type of dam	Power (MW)	Energy (GWh/yr)
In operation	Borçka Dam and HPP	Artvin	Rock-fill dam	300	1039
	Muratlı Dam and HPP	Artvin	Rock-fill dam	115	444
	Tortum I HPP	Erzurum	Without storage	26.18	85
Under construction	Deriner Dam and HPP	Artvin	Concrete arch dam	670	2118
Final design report ready	Yusufeli Dam and HPP	Artvin	Rock-fill dam	540	1705
	Artvin Dam and HPP	Artvin	Arch gravity dam	332	1026
Feasibility report ready	Laleli Dam and HPP	Erzurum	Rock-fill dam	99	245
	İspir Dam and HPP	Erzurum	Rock-fill dam	54	327
	Güllübağ Dam and HPP	Erzurum	Concrete arch dam	84	285
	Aksu Dam and HPP	Erzurum	Rock-fill dam	120	344
	Arkun Dam and HPP	Erzurum	Rock-fill dam	222	788
	Altıparmak Dam and HPP	Artvin	Concrete arch dam	50	200
	Olur Dam and HPP	Erzurum	Rock-fill dam	65	242
	Ayvalı Dam and HPP	Erzurum	Rock-fill dam	125	409
	Bayram Dam and HPP	Artvin	Rock-fill dam	68	250
	Bağlık Dam and HPP	Artvin	Concrete gravity dam	59	226
	Tortum II HPP	Erzurum	Without storage	8	42.3
	Erenler HPP	Artvin	Without storage	19	89
Master plan ready	İkizkavak HPP	Artvin	Without storage	20	73
Preliminary report ready	Çayaşan HPP	Erzurum	Without storage	17	84
	Ardıçlı HPP	Erzurum	Without storage	6.25	20.08
	Çayırözü HPP	Erzurum	Without storage	3.92	13.32
	Özlüce HPP	Erzurum	Without storage	18	61
	Yedigöl HPP	Erzurum	Without storage	11	42
	Aksu HPP	Erzurum	Without storage	21	94
	Sırakonaklar HPP	Erzurum	Without storage	11	43
	Öğdem HPP	Artvin	Without storage	18	69
	Ardanuç HPP	Artvin	Without storage	8.3	21.7
	Meydancık HPP	Artvin	Without storage	17	65.87
	Şavşat HPP	Artvin	Without storage	11	41.14
	Aydın HPP	Artvin	Without storage	1.5	5.15
	Dipçin HPP	Artvin	Without storage	4.14	14.47
	Kızıl HPP	Erzurum	Without storage	1.46	5.7
	Kocaklar HPP	Erzurum	Without storage	3	10.63
	Şehir HPP	Erzurum	Without storage	1.24	6.14
	Tapsur HPP	Erzurum	Without storage	1.65	6.28
	Tünkeş HPP	Erzurum	Without storage	1.06	4.38
Total hydropower potential				3132.70	10,545.16

installed capacity of 13 MW and energy generation of 45.2 GWh/yr, is a project improved by private sector and signed water right consensus. Besides, 3 projects having installed capacity of 18.8 MW and energy potential of 67.3 GWh/yr, which are preliminary report ready, will be developed within borders of Bayburt Province. 55 HPPs have been planned by private sector in Erzurum Province. Water Right Consensus of 20 of these projects, which have installed capacity of 320 MW (630 GWh/yr) are signed, 21 projects with feasibility report ready and 14 projects with preliminary report ready have energy generation of about 795 GWh/yr and 122 GWh/yr,

Table 3
Total energy potential of the Çoruh river basin [22,31,32].

Province	Status of project	Number of project	Power (MW)	Energy (GWh/yr)
Artvin	Signed Water Right Consensus	9	123	418
	In operation	2	5	10
	Feasibility report ready	30	432	1509
	Preliminary report ready	19	99	273
Bayburt	Signed Water Right Consensus	1	13	45.2
	In operation	–	–	–
	Feasibility report ready	–	–	–
	Preliminary report ready	3	18.8	67.3
Erzurum	Signed Water Right Consensus	20	320.17	629.66
	In operation	–	–	–
	Feasibility report ready	21	251.2	795.2
	Preliminary report ready	14	55.01	121.54
Hydro potential which will be made by corporate bodies (private sector)			1317.18	3868.90
Hydro potential within the scope of the Çoruh Basin Development Plan			3132.70	10,545.16
Total hydro potential of Çoruh river basin			4449.88	14,414.06
Total thermic potential of Çoruh Basin			50	300
Total energy potential of Çoruh river basin			4499.88	14,714.06

respectively. Finally, total evaluable hydropower potential of Çoruh river basin reaches 14.414 GWh/yr when all these projects planned are taken into consideration. This value corresponds to 40.2% of the annual hydroelectric energy production of the Turkey which is 35.851 TWh/yr in 2007 and also 11.1% of the theoretical hydro potential (nearly 129.9 TWh/yr). Total energy generation potential of Çoruh river basin is 14.714 TWh/yr together with thermal potential in operation with capacity of 300 GWh/yr (Table 3).

4. The importance of Çoruh river basin and development projects

The planned development will result in a total annual energy production of 10.55 TWh with the implementation of 3132.7 MW of hydro capacity on the Çoruh river basin. This capacity corresponds to about 6.3% of Turkey's total electricity generation (167.9 TWh in 2006) and 24.1% of the present annual hydroelectric energy production (43.8 TWh in 2006) of Turkey. This Development Plan, spanning close to 10 years, are expected to have significant positive socio-economic impacts primarily for this underdeveloped region and the affected communities. First of all, the chain of these projects will contribute into reducing energy inefficiency (Turkey's energy import is about 73% in 2006) being an ever-increasing important problem for Turkey. Besides, it is supposed that this development plan will advocate being implemented socio-economic projects planned to be done in the East Black Sea Region which is an underdeveloped area of Turkey.

One of the most remarkable properties of dams built in Çoruh river basin is that there are not numerous settlement and agricultural area within dam reservoir. Other considerable property is that dam reservoir area is quite suitable for building dam in respect to tectonic and topographic characteristics of the basin. High water power potential of Çoruh river and its tributaries is a great advantage for not only region but also Turkey's economy.

Taking to consideration floods becoming fact in the past, it is expected that projected dams will be extremely important in terms of not only energy generation but also floods.

The realization of the hydropower projects in the Çoruh river basin may initiate investments, including tourism, in the area. Formation of the reservoir may create new opportunities for recreation and tourism. Summer season when the reservoirs is operated at the highest operation level with a constant water surface elevation is considered to be most appropriate for the working of recreational facilities such as sailing and similar sports. Deriner and Borçka dam reservoirs which are built or building close to Artvin province may be tourism centers where all kinds of aquatic or water sports will be done.

It is supposed that dam reservoirs will compose a high potential resource for culture fishing. For this reason, before construction of all dams has not been completed, an aquaculture production center may be constituted for seed fishes and culture fishing. Also, dam reservoirs will be a good recreation area and feeding ground for migratory birds and regional fauna. With arising of dam reservoirs, recreation potential of the basin which exists will raise a lot. This potential will be an important sector which contributes into economy of the basin or region with a regular planning when infrastructure activities have been completed.

A big part of existing highway in the basin take part the bank of Çoruh river valley and waterway located in valley. For this reason, when dam constructions have been completed these existing roadways will be covered with dam reservoir. Therefore, new variant roads will have been built. These relocation roads are mainly planned parallel to the reservoir boundaries. Thus, new highway (Fig. 9) that will have been constructed due to dams will shorten existing road and rise as existing road. In other words, Rize-Artvin-Erzurum relocation roads will be relatively more reliable for passengers and these travellers will have opportunity of faster highway transportation. For example, the Artvin-Erzurum relocation road is 31 km long, while Artvin-Bayburt is 55 km long. The width of the corridor to be expropriated is 50 m for Artvin-Erzurum relocation road and 35 m for Artvin-Bayburt. In addition, based on field requirements this 35–50 m width may be increased (e.g. for slopes). On the other hand, in the event of completing Black Sea Coastal Highway and these new dam roads, importance of Hopa Harbor will increase and this will significantly contribute into economy of East Black Sea Region under favour of national and international trade.



Fig. 9. A view from tunnel and highway built the Çoruh river basin.

The Çoruh basin has been exposed to serious population decrease in the last twenty years due to migration. Population which was 527,809 people in 1980 went back 432,259 ones decreasing approximately 100 thousand people (95,500) in 2000 [26]. Population of the basin in 2007 became 330,699 people going back further in contrast with 2000 year. It is quite important that projects within the context of Çoruh River Basin Development Plan are completed to prevent this population migration and to raise economic income level of the region. When these projects are completed or while they are in the phase of under construction, these dam and HPPs and their construction will provide possibility of employment and various profession branches will able to develop by means of new dam and HPPs.

Although an agreement between Turkey and Georgia was reached on the use of water of the Çoruh river, allocating half of the average surface water flow to each country in 1925 [33], there is no comprehensive bilateral agreement on the management of the Çoruh river between Turkey and Georgia. Today, Turkey is not only a principal political and a strategically important partner for Georgia in the region, but also a very important trading partner. Economic exchange between both countries has experienced an impressive increase in the last decade with the consequence that Turkish–Georgian trade constitutes 17% of the total international trade volume of the Georgian economy [19].

Çoruh river is, today, least problem river of Turkey as compared with Turkey's other trans-boundary waters. Although concerns that completed or planned dams on the Çoruh river within the scope of Çoruh Basin Development Plan will affect the Batumi delta of Georgian shore exist, the Çoruh river is single problem-free trans-boundary water of Turkey because it is not expected that any problem between both countries (Turkey and Georgia) will arise due to their political and economic relations. In addition, water which has been accumulated in reservoirs of these dams will only be used within the aim of energy generation, in other words it will not be used for irrigation. As the Çoruh river flows towards areas

which have humid climate whither water need is very little from semi-arid areas, it is realized that this situation will not compose any international problem in respect to water use [26].

5. Conclusions

The main indigenous energy resources of Turkey are hydro and lignite. Turkey has no big oil and gas reserves. Almost all oil and natural gas is imported, as is high quality coal. But Turkey has an abundant hydropower potential to be used for generation of electricity and must base its energy strategy on developing the whole hydroelectric potential as soon as possible. In order to avoid foreign dependency, Turkey must investigate and evaluate new and renewable energy resources (hydro, solar, wind, wave, geothermal, etc.).

In this article, firstly the hydroelectric energy potential and its development both in Turkey and the World are examined. Then, Çoruh river basin has been chosen being case study to carry out some examinations concerning its potential. For this purpose, this paper analyses general characteristics, climate and water resources, current water usage status, and energy potential of the Çoruh river basin. In addition to this, the Çoruh Basin Development Plan, projects developed by private sector, and the importance of Çoruh river basin are discussed and evaluated. The main conclusions that can be drawn from the present study are listed below:

- The fuel (water) for hydropower plants is renewable, and is not subject to fluctuations in market conditions. Hydropower can also represent energy independence for many countries. Today, hydropower provides about 26% of the Turkey's electricity generation.
- Despite the rather small drainage basin area, the Çoruh river has high hydropower production potential due to the topographic conditions and, in particular, the sharp fall of the river from high mountains to sea level. Only a minor share of the river's water is used for economic or social purposes. The Çoruh has (according to DSI estimates) the potential to provide some 8.3% of the usable hydroelectric power in the country, which, to date, remains largely untapped.
- Finally, total evaluable hydropower potential of Çoruh river basin reaches 14.414 GWh/yr when all projects planned in scope of Çoruh Basin Development Plan and developed by private sector are taken into consideration. This value corresponds to 40.2% of the annual hydroelectric energy production of the Turkey which is 35.851 TWh/yr in 2007 and also 11.1% of the theoretical hydro potential (nearly 129.9 TWh/yr). Total energy generation potential of Çoruh river basin is 14.714 TWh/yr together with thermal potential in operation with capacity of 300 GWh/yr. For this reason, development studies and investments in the hydropower sector should be encouraged and supported and these projects should be put into operation as soon as possible.

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